THE EFFECT OF MAGNIFICATION ON VISUAL TASKS: I. VISUAL FORM COMPARISON

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ABSTRACT

The effect of magnification on a task requiring visual form-comparison was investigated. The critical detail was such as to require close attention, but even in the smallest size was above the acuity threshold. It was found that, for this type of task, speed of performance increased with increasing size up to an intermediate level, and remained constant for increases beyond that level.

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I. VISUAL FORM COMPARISON

I. INTRODUCTION

Magnification is effective in bringing detail above the threshold of perception, but various instrumental factors such as photographic grain, attenuation of density gradients, and occluding of surrounds, impose limits. It can be assumed that, independently of such factors, extreme magnifications requiring large head movements and the viewing of peripheral areas at oblique angles would impair perception. The question remains whether more realistic degrees of magnification might result in a loss of perceptual efficiency on some tasks. The present study was directed at this question. This report covers Part I of the study, in which the main visual task was one requiring the comparison of detail. Part II, in which the task required perceptual integration, will be reported later.

II. EXPERIMENTATION

A. Exploratory Phase

The first step in the program was the scanning of a number of types of visual display under a range of magnifications. A loss of perceptual effectiveness with increased magnification was suggested in some instances, but the observations were by no means clear-cut nor consistent. The next step was a small scale experiment (Experiment I below) with stimulus material on hand which provided the basis for a scorable visual task. With this it was feasible to obtain meaningful quantitative data, though it proved desirable to develop new stimulus material for subsequent steps in the program.

1. Experiment 1 - Numeral Identification

In this experiment the effect of magnification on a numeral-identification task was tested. The stimulus material was an array of printed numbers projected on a wall screen. The Subject's task was to count the number of appearances of selected numerals (e.g., "2", "4" and "7"). Six Subjects participated. Scoring was in terms of time and errors.

a. Apparatus

Transparencies of the number arrays were prepared and displayed on the screen by means of a slide projector. Size of the display was changed by varying projection distance. The Subject sat in a fixed position, about 5 ft. from the screen, and slightly off center to avoid obstructing the beam. The room was partly darkened.

Three sizes were used, covering a range of about 8/1 in linear dimensions. In the smallest size the number array measured about 13 by 17 in., in the intermediate size, 27 by 36 in., and in the largest size 49 by 65 in. Corresponding visual angles subtended by an individual numeral in the vertical dimension were 31', 1° 6' and 1° 58'. In the smallest size, the numbers corresponded approximately to capital letters in 12-point type at reading distance, and could be presumed to be safely above the acuity threshold.

Illumination on the screen was set at 0.8 foot-candles for all magnifications.

b. Experimental design and procedure

Individual numerals occurred with different frequencies in the array. Three sets of three numerals each were selected which had about the same total frequencies. Each Subject was asked to count the three numerals in one set under each of the three magnifications. The numeral sets were rotated among magnifications, and the magnifications were rotated among serial positions by Subjects. Time to make the count was recorded by individual numerals.

c. Results

Results can be stated concisely. Mean time scores, by sets of three numerals, for the group of six Subjects, were: at the smallest magnification, 41.7 sec., at the intermediate magnification, 40.0 sec., and at the largest magnification, 41.3 sec. The corresponding accuracy scores were 91%, 95% and 97%. None of the differences was significant. Especially there was no evidence of impairment with increased magnification. A more definitive conclusion, however, would require a more adequate experiment, and for this purpose the new stimulus material was prepared.

B. The Main Experimental Series

The new stimulus material was used in the remainder of the experiments here reported. A new projection system was constructed, for greater control and flexibility, and used throughout except in Experiment No. 4. The stimulus material, projection apparatus, and standardized features of procedure will be described for the series as a whole. Modifications and supplementary details will be given by expsriments.

1. Stimulus material

A task was desired which would require attention to detail, but in which the detail would not place a premium on acuity. For this purpose the test forms shown in Figure 1 were designed. The generalized form consisted of two parts, body and base. Each part could have one of two shapes, triangular and rhombic. This made possible four combinations,

all of which are shown in Figure 1. Displays of four forms were prepared, which included two conditions: (a) all four forms identical, and (b) one form different from the other three. On a given display, the Subject was required to make a same-different judgment. The four forms were used to produce four "same" displays. All possible "different" displays were prepared, from sets of three identical forms and one different form, the latter of which might appear in any one of the four positions. This gave 48 "different" arrangements. For use in the experimental routine the 48 "different" combinations were balanced by 48 "same" combinations to make a total of 96 stimulus items. To accomplish this it was, of course, necessary to repeat each of the four basic "same" patterns 12 times. The 96 items were divided into sub-sets equated with respect to "same-different" and other features of pattern type. Within an experiment, sub-sets of items were assigned to experimental conditions.

Forms were equal in height and width. The center-to-center distance between forms on the adjacent corners of a display was 1.36 the width of a form. Figure 1 correctly represents the stimulus material in this respect, but not in the selection of forms.

2. Apparatus

The four-form displays were prepared, in several sizes, on photographic transparencies, and shown on a rear-projection screen. The Subject sat in a darkened booth and viewed the screen at 14 in. The forms appeared dark on a light ground approximately 12 in. square.

The projector was provided with a selenoid-operated shutter with which an electric timer was synchronized. An Experimenter's finger key opened the shutter and started the timer. A Subject's response key closed the shutter and stopped the timer.

3. Procedure

A trial consisted of a stimulus pattern calling for a same-different judgment. To start a trial, the Experimenter gave a warning signal, then opened the shutter and started the clock. The Subject responded as soon as he thought he could make a correct judgment. The response consisted of pressing the response key and simultaneously announcing "same" or "different". The Experimenter recorded the response and the time, and then positioned the slide for the next trial.

4. Experiment 2 - Pilot Experiment, Form Comparison, Transillumination

Experiment 2 was a pilot experiment with the new visual task. Two Subjects who were sophisticated with respect to the problem and two naive Subjects participated.

Three magnifications were used. For the smallest, the center-to-center distance between adjacent forms on the screen was 0.70 in.; for the next, 2.2 in.; and for the largest, 4.8 in. Corresponding visual angles for the size of a single form were $2^{\circ}8'$, $6^{\circ}38'$ and $14^{\circ}28'$. Luminance on the central area of the screen was 524 foot-Lamberts.

a. Experimental Design

The two naive Subjects were given 48 trials on each of the three magnifications. Order of magnifications was balanced on an a-b-c-c-b-a basis for each Subject. The two sophisticated Subjects had 48 trials on each of the two extreme magnifications only, in balanced order.

For the naive Subjects, the regular trials were preceded by 24 practice trials. The other Subjects, who had previous experience in the test situation, were given five warm-up trials.

b. Results

For the two naive Subjects, mean time scores, in increasing order of magnification, were 1.06, 1.14, and 1.15 sec. For the sophisticated Subjects, mean time scores on the smallest and largest magnifications respectively were 1.37 and 1.31 sec. Errors were too few to permit meaningful comparisons. The time differences between magnifications were clearly insignificant. The experiment demonstrated that the stimulus material and procedure were suitable for Phase I of the study.

5. Experiment 3 - Form Comparison, Transillumination

This experiment was planned to provide more definitive data. To the three magnifications of Experiment 2 a still smaller size was added. Sixteen new Subjects, equally divided by sex, were used.

The four stimulus sizes had center-to-center distances of 0.26, 0.70, 2.2 and 4.8 in., with corresponding visual angles for a single form of $47'$, $2^{\circ}8'$, $6^{\circ}38'$, and $14^{\circ}28'$. All displays made possible by the various form combinations were used.

a. Experimental Design

Each Subject had a sub-set of 48 stimuli at each of the four magnifications, the sets being rotated among the magnifications for different Subjects. Serial order of magnifications was also balanced among Subjects. All balancing was arranged within each sex group separately.

Subjects were shown a demonstration card to acquaint them with the type of stimulus patterns, and instructed about the task and the procedure. They were then given 32 practice trials. An experimental period took a little less than an hour.

b. Results

Mean time scores per trial, for individual Subjects at each of the four magnifications, are recorded in Table I A. Errors are shown as percentages of the 24 items at a given magnification, for each Subject, in Table I B.

A variance analysis of the time scores found magnification to be significant at the 0.05 level, sex to be not significant. Mean time scores, for the four magnifications in increasing order of size, were 1.52, 1.38, 1.38 and 1.41 sec. Differences between the three larger sizes were not significant, as in Experiment 2, but the small size added in Experiment 3 was apparently more difficult.

A rigorous analysis of error scores did not seem to be justified, because of their low incidence and spotty distribution. Total errors expressed as percentages of total trials, for the four magnifications in increasing order of size, were 6.5, 4.7, 2.1 and 4.4%. One extreme Subject was responsible for about a third of all the errors. With this case eliminated the corresponding figures were 5.5, 2.9, 1.3 and 2.1 %. The general pattern was not inconsistent with that of the time scores.

In a separate analysis of time scores the "same" and "different" items were compared. The former were the more difficult, the means being 1.62 sec. for "same" and 1.23 sec. for "different", with only one of the 16 Subjects showing an identical score for the two conditions, and no Subject showing a reversal.

6. Experiment 4 - Form Comparison, Front Illumination

In view of the fact that, in Experiment 3, the smallest size was measurably more difficult than the others, it seemed in order to ask whether the nature of the viewing situation was contributing to the difficulty at the lower end of the size range. The surface character of a transilluminated diffusing screen is noticeably different from that of a paper surface, and the sudden transition from the dark inter-trial condition to high screen illumination when the shutter was opened might have interfered with the perception of detail. A new viewing situation was therefore developed, for which the stimulus material was prepared in the form of photographic prints, and front instead of rear illumination was provided. A further feature was an illuminated standby field at which the Subject looked between trials.

Three magnifications were used. As it was desired to explore the lower end of the previous magnification range, the two smallest magnifications from Experiment 3, and one still smaller, were selected. The three stimulus sizes had center-to-center distances of 0.14, 0.26 and 0.70 in., the corresponding visual angles for a single form being 25', 47' and 2°8'. Seventy-two of the 96 stimulus items were used, in balanced sub-sets.

Eighteen new Subjects participated, equally divided between the sexes.

a. Apparatus

The apparatus was so arranged that the Subject viewed the stimulus material through a first-surface mirror. The line of sight was horizontal, the stimulus card was positioned face up on a horizontal surface below eye level, and the mirror was inclined at approximately 45°. The mirror was pivoted to swing through a small angle, and in its resting position it brought into view a plain white card which served

as the standby field. The mirror position was controlled by a selenoid activated by the Experimenter's finger key, and thus served as a shutter, exposing the stimulus card when a trial was started. The Subject's response key released the mirror to the standby position. The electric timer was synchronized with the mirror. Small lamps positioned laterally produced a target-field luminance of 260 ft-L and a standby field luminance of 318 ft-L. The Subject looked through an aperture in the front wall of the housing which enclosed the card holder, standby field, mirror, and lamps. Viewing distance was 14 in. as in the projection system of Experiments 2 and 3. At that distance, an illuminated area about 4 in. high by 8 in. wide was visible.

b. Experimental Design

Each Subject had a sub-set of 24 stimulus items at each of the three magnifications, the sets being rotated among the magnifications for different Subjects. Serial order of magnifications was also balanced among Subjects. All balancing was arranged within each sex group separately.

Subjects were given 24 practice trials. An experimental period took a little less than an hour.

c. Results

Mean time scores per trial, for individual Subjects at each of the three magnifications, are recorded in Table II A, and errors in percentage terms in Table II B.

As in Experiment 3, a variance analysis of the time scores found magnification to be significant (at better than the 0.01 level) and sex to be not significant. Group-mean time scores, for the three magnifications in increasing order of size, were 1.79, 1.61 and 1.52 sec. Both differences between adjacent size steps were significant. This confirms the finding of Experiment 3 for the two larger sizes, indicates a continuation of the trend for the smaller size added in Experiment 4, and suggests that, for the visual judgment required, the two viewing situations were substantially equivalent. The absolute scores were somewhat higher in Experiment 4, but that can probably be attributed to the greater inertia of the mirror system in that experiment than of the shutter in Experiment 3.

Errors were somewhat more uniformly distributed among Subjects than in Experiment 3, but the magnification differences were not significant. The error percentages, in increasing order for the three magnifications, were 5.1, 4.2 and 6.3%.

As in Experiment 3, "same" items were more difficult than "different" items, the respective time scores being 1.85 and 1.41 sec., with no reversals by individual Subjects.

7. Experiment 5 - "Expanded" Display

The first four experiments produced no data suggesting impairment of performance from increased magnification. In a previous investigation done for another purpose (1), however, it had been found that increasing the distance between the elements of a display, though the elements themselves were not magnified, did increase the time required for a visual task. This raised the question whether the same effect would be obtained with the type of stimulus material used in the present study. Experiment 5 was done to answer this question.

Three stimulus conditions were included, two being magnifications previously used, the third being a display consisting of forms the same size as those in the smaller magnification but spaced like those in the larger magnification. The largest and next to smallest of the magnifications from Experiment 3 were selected, because these provided the greatest range of magnification not differentiated by the Subjects' time scores. The center-to-center distances on the screen were 0.70 and 4.8 in., the corresponding visual angles for single forms being $2^{\circ}8'$ and $14^{\circ}28'$. For the third condition new slides were prepared, with forms in the $2^{\circ}8'$ dimension but with center-to-center spacing of 4.8 in. This will be referred to as the expanded condition.

Twelve Subjects participated, equally divided between the sexes; each sex group included three individuals experienced in one of the previous experiments and three without experience.

The rear-projection screen was used as in Experiments 2 and 3. Screen luminance was 300 ft-L.

a. Experimental Design

The selection of stimulus items and experimental design were the same as in Experiment 4. Balancing was arranged within each sex and experience group separately.

b. Results

Mean time scores per trial, for individual Subjects under each of the three conditions, are given in Table III A, and errors in percentage terms in Table III B.

In time scores the two magnifications were not significantly different, which confirmed the results of Experiments 2 and 3. Time for the expanded condition, however, was significantly different, at the 0.01 level, from that for either of the two magnifications. The means were, for the small magnification, 1.11 sec., for the large magnification 1.18 sec., and for the expanded condition 1.38 sec. This reinforces the finding in the separate study previously referred to that the expanded condition makes some tasks measurably more difficult.

Errors as usual were few and did not differentiate among conditions. The error figures, in per cent of total trials, were, for the small magnification, 6.2%, for the large magnification, 6.6%, and for the expanded condition, 6.3%.

The sexes were not significantly different. The experienced Subjects were faster than the new but this difference also proved to be not significant.

The "same" items were more difficult than the "different" items as usual, with only one reversal among the 12 Subjects, the respective mean time scores being 1.37 and 1.07 sec.

III. DISCUSSION

The range of sizes ivestigated with the form-comparison task was about 35/1. On the basis of the perceptual performance data, this range can be divided into two parts. In the lower part, defined by the first three sizes with a range of about 5/1, performance improved with increasing size. In the upper part, defined by the three largest sizes with a range of about 7/1, performance was constant.

As a stimulus pattern enlarges from a very small size, with details emerging from a sub-threshold level, perception can be expected to improve over some region. The limit of this region will probably depend on the pattern. In our smallest stimulus patterns an individual form subtended a visual angle of 25'; this is comparable to a capital letter in 10-point type viewed at 14 in. The definitive characteristics of our test forms were, of course, different from those of letter symbols; a letter is differentiated to a large extent by its overall configuration, while our test forms had to be differentiated by secondary features. This critical detail, however, was well above threshold, as judged by the observation that any particular detail was clear and unmistakeable when attended to carefully. Nevertheless the perceptual judgments were made faster as size increased up to a visual angle of $2^{\circ}8'$ for a single form. This is about the size of a capital letter in 48-point type. For patterns characterized by other types of detail, the limit of improvement with increasing size might be at either a higher or lower level. For the numeral identification task, in fact, the data indicated that the limit was not above 31', equivalent to about 12-point type.

For light on the question whether increasing magnification might impair perception, we can turn to the region above the limit of improvement. In this region no evidence was found, with either the form-comparison task in a size range of 7/1 at high luminance, or the numeral identification task in a size range of 8/1 at low luminance, for such impairment.

Evidence for impairment on the expanded display, on the other hand, was clear cut. What happens, then, in the one case and not in the other? In an expanded display, with size of detail kept small, good fixation can be assumed to be necessary for accurate perception; greater spacing of the elements, however, necessitates more time spent in transitional eye movements, and possibly more time for the fixation-zeroing process as a result of high velocity achieved in the long swings.

If the same precision of fixation were achieved in a magnified as in an expanded display (the center-to-center distances being the same) a corresponding increase in total time might be expected. Since we did not find this effect for the magnified display, it can reasonably be inferred that increased size of the elements permitted a more peripheral perception, with the fixation pattern proportionately abridged.

A secondary point of interest was the longer time required for "same" than for "different" judgments. Two factors were probably involved: (1) if the first two elements attended to happen to be different a judgment could be made immediately, but a "same" judgment could not be made until all four elements had been attended to; (2) by experimenters' introspections, dissimilarity seemed relatively easy to apprehend; similarity, on the other hand, did not have the same psychological impact, and more time was spent in verification.

It would be unsafe to generalize findings for the effect of magnification on form detail to other types of visual task. For this reason a task requiring perceptual integration was investigated in a second phase of the program. Results from that phase (of which the analysis has not been completed) do in fact indicate a different effect. This will be covered in a second report.

IV. CONCLUSIONS

Increase in magnification, over a range of relatively small sizes, was found to improve performance on a form-comparison task, and over a range of larger sizes, to have no effect. In no part of the range investigated was impairment produced.

BIBLIOGRAPHIC REFERENCES

1. Crook, M. N., Bishop, H. P., Feehrer, C., and Wade, E. A. Luminance reintensification at frequencies from 40 to 300 cycles per second as a factor in the reading of simulated visual displays. US Air Force Command and Control Development Division, Operational Applications Office, Bedford, Mass. AFCCDD-TR-61-5. October, 1960.

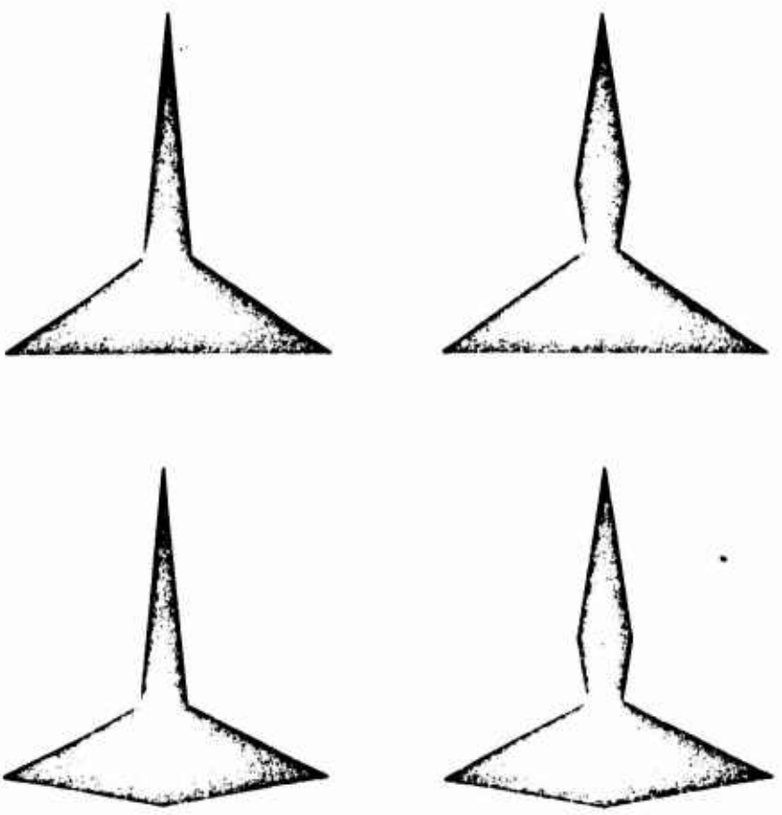

Figure 1. Stimulus forms used in Experiments 2 to 5.

TABLE I

MEAN TIME AND ERROR SCORES ON FOUR MAGNIFICATIONS (EXPERIMENT 3)

	A TIME (seconds)				B ERRORS (%)			
	MAGNIFICATION*				MAGNIFICATION*			
SUBJECT	47'	2°8'	6°38'	14°28'	47'	2°8'	6°38'	14°28'
1	1.58	1.52	1.32	1.48	0	0	0	4.2
2	.93	.94	.89	.85	16.7	12.5	8.3	0
3	1.43	1.29	1.67	1.37	8.3	12.5	0	16.7
4	1.49	1.34	1.17	1.30	0	4.2	0	0
5	1.79	1.60	1.55	1.75	4.2	0	0	4.2
6	2.15	1.90	1.83	1.65	0	0	0	0
7	.94	.79	1.09	1.14	4.2	0	4.2	0
8	1.26	1.43	1.28	1.57	0	0	0	0
9	1.31	1.44	1.49	1.30	8.3	0	0	0
10	1.96	1.72	1.57	1.83	4.2	0	0	0
11	1.85	1.62	1.75	1.71	0	0	0	0
12	1.65	1.60	1.64	1.70	4.2	0	0	4.2
13	1.95	1.60	1.52	1.54	20.8	8.3	4.2	0
14	.58	.50	.52	.53	16.7	29.2	12.5	37.5
15	1.84	1.54	1.55	1.45	0	0	0	0
16	1.60	1.22	1.20	1.46	16.7	8.3	4.2	4.2
Mean	1.52	1.38	1.38	1.41	6.5	4.7	2.1	4.4

* Magnifications are in terms of visual angle subtended by one form.

TABLE II

MEAN TIME AND ERROR SCORES ON THREE MAGNIFICATIONS (EXPERIMENT 4)

	A TIME (seconds)			B ERRORS (%)		
	MAGNIFICATION*			MAGNIFICATION*		
SUBJECT	25'	47'	2°8'	25'	47'	2°8'
1	1.72	1.53	1.48	0	0	8.3
2	1.55	1.72	1.37	4.2	0	0
3	2.06	1.94	1.76	0	4.2	4.2
4	1.49	1.42	1.46	0	0	0
5	1.81	1.84	1.44	8.3	0	4.2
6	1.69	1.29	1.34	4.2	4.2	16.7
7	1.22	1.12	1.09	8.3	12.5	12.5
8	2.32	2.32	2.08	0	0	0
9	1.29	1.21	1.19	0	8.3	4.2
10	3.01	2.87	2.54	0	4.2	12.5
11	1.34	.95	.90	20.8	8.3	16.7
12	1.75	1.23	1.47	4.2	4.2	4.2
13	2.38	1.72	1.64	0	0	4.2
14	2.14	2.27	1.72	4.2	4.2	0
15	1.19	1.08	.99	20.8	0	12.5
16	1.93	1.69	1.73	4.2	4.2	8.3
17	1.48	1.29	1.48	12.5	8.3	4.2
18	1.80	1.43	1.68	0	12.5	0
Mean	1.79	1.61	1.52	5.1	4.2	6.3

* Magnifications are in terms of visual angle subtended by one form.

TABLE III

MEAN TIME AND ERROR SCORES ON THREE CONDITIONS (EXPERIMENT 5)

	A TIME (seconds)			B ERRORS (%)		
	MAGNIFICATION*			MAGNIFICATION*		
SUBJECT	2°8'	14°28'	EXPANDED**	2°8'	14°28'	EXPANDED**
1	.95	.75	.86	8.3	8.3	4.2
2	1.27	1.42	2.01	4.2	0	4.2
3	1.22	1.18	1.55	0	0	0
4	.87	.79	.92	12.5	8.3	16.7
5	.81	.84	1.20	4.2	4.2	12.5
6	.86	.91	1.07	8.3	16.7	12.5
7	1.24	1.55	1.49	0	0	4.2
8	.97	1.04	1.16	16.7	25.0	12.5
9	.81	.90	1.22	4.2	4.2	4.2
10	1.26	1.41	1.44	0	8.3	0
11	1.50	1.34	1.75	16.7	0	4.2
12	1.53	1.98	1.86	4.2	0	0
Mean	1.11	1.18	1.38	6.6	6.2	6.3

* Magnifications are in terms of visual angle subtended by one form.

** In the expanded condition, size of elements corresponded to that in the smaller magnification but spacing corresponded to that in the larger.